Ground Source Heat Pumps – history, development, current status, and future prospects

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Early „shallow geothermal“ applications

The fact that the temperature in the underground is rather stable is used by animals since there is life on land, and since prehistoric times also by human beings, hiding in holes or caves to

• keep cool in hot climate,
• or warm in cold winters,
• or storing food at steady, low temperatures

Similar geology in distant regions has led to very similar solutions

Zelve, Kappadokia, Turkey

Bandelier, New Mexico, USA
Early „shallow geothermal“ applications

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Deep cellars for wine, food etc. are widely used, and houses built into the ground are part of ancient Northern architecture

Underground storage shed in Emmaboda, Sweden
Understanding the shallow geothermal realm

The temperature regime in the underground is controlled by the storage capacity of the earth, reacting to external influences from the surface (climate) and from below (geothermal heat flux).

- The first to put numbers to the effect of dampening temperature changes were Buffon in 1778, A. von Humboldt in 1799 (0.04 K change only in the deep cellar of the Paris Observatoire), Everett and Thompson in Edinburgh in the 19th century.

![Measurement of ground temperature in Edinburgh, average values 1838-1854, after data from Everett (1860)](image_url)
Understanding the shallow geothermal realm

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- The first to put numbers to the effect of dampening temperature changes were…
- The geothermal heat flux was stated by Kircher in 1665, and expressed in numbers e.g. by Buffon in 1778, Cordier in 1827, Bischof in 1837, Lebour in 1822, …

Geothermal gradient as to measurements in the silver-lead-copper Mines in Giromagny, after data from Buffon (1778)
Understanding the shallow geothermal realm

The temperature regime in the underground is controlled by the storage capacity of the earth, reacting to external influences from the surface (climate) and from below (geothermal heat flux).

Original plotter graph from 1987 showing the undisturbed temperature development along a borehole 50 m deep over one year, from August 1986 to August 1987, in the Schwalbach GSHP research station.
How to make use of shallow geothermal energy?

In order to actively use the shallow underground for energy production or storage, a tool is required for changing temperature: the heat pump to increase it, and the chiller (or a heat pump in reversed mode) for decreasing temperature.

• An early vision of such a machine with two cylinders in series was given already by Thomson (1853)

• Today it is generally accepted that the first practical application of the heat pump principle was made by Peter von Rittinger in 1857, using vapour compression in a closed batch circuit to evaporate water and thus produce salt from concentrated brine in the Ebensee salt factory in Austria.

Rittinger (1855): ‘Steam can generate mechanical work, but hardly any physicist will doubt the sentence expressed in the reversed sense, mechanical work can generate steam’.
Beginnings of heat pumping / GSHP in Europe

After early theoretical ideas, practical application started in 1938

• Thomson (1853): ‘On the economy of the heating or cooling of buildings by means of currents of air’

• Zoelly applied for a patent on 13\textsuperscript{th} February 1912 in which a ground-source heat pump is described; it was granted in 1919 as Swiss patent No. 59350

• A river-water based heat pump was installed in the Zurich town hall, Switzerland, in 1938; other similar plants followed

• The first truly geothermal heat pump in Europe seems to be a groundwater heat pump in Thun, Switzerland, about 1950 (Zogg, 2008)
The first GSHP boom in North America

In the 1940s, the development started full force in the USA

- First true GSHP, using horizontal loops in the ground, in Oct. 1945 in Indianapolis

System schematic of the first GSHP as in Crandall (1945), above, and re-drawn from Sanner (2005), right
The end of the first GSHP episode in the 1950s

The technology of ground source heat pumps was somehow mastered in the early 1950s, both in North America and Europe (at least in Switzerland).

However, with low prices for coal, and fuel oil becoming the main source for heating in the later 1950s, any economic advantage vanished, and the market faded away.
The second GSHP episode in Europe, 1970s-80s

The technical development re-started already at oil prices still low.

• A first ground-source heat pump in Germany, using horizontal loops, became operational in 1969 (Waterkotte, 1972).

• Groundwater wells as heat source for heat pumps followed soon after (e.g. Drafz, 1972).

• The evaluation of the number of publications on the different types shows clearly that BHE came on the market several years later.
The second GSHP episode in Europe, 1970s-80s

In October 1973 the OPEC decided on a reduction of oil supply to the Western countries as retribution to the West supporting Israel in the Yom-Kippur-war.

Oil prices soared, and alternatives were sought.
The second GSHP episode in Europe, 1970s-80s

After 1973, heat pump development took off.

It is also interesting to see that environmental aspects were part of the spectrum of publications almost from the beginning, as well as permitting issues (at least in Germany).

First regulatory document on GSHP in Germany:
LAWA (Länderarbeitsgemeinschaft Wasser) 1980
Mainly groundwater heat pumps, but first BHE are mentioned.
Capacity stated: 60-100 W/m

Graph of BHE in LAWA (1980)
The second GSHP episode in Europe, 1970s-80s

Heat pumps were available quite in time for the second oil price crisis in 1979/80, caused by the revolution in Iran and the subsequent Iran-Iraq-war.

values for Illinois Crude Oil, after data from http://inflationdata.com
The second GSHP episode in Europe, 1970s-80s

Borehole heat exchangers had their start just during the boom.

• First experiments are reported from UK, Netherlands and Sweden.
• In Germany, first BHE were installed in the late 1970s, but not documented in publications; typical depth 50 m.

Photos from a brochure of 1981:
• Drilling,
• Coaxial BHE (corrugated stainless steel),
• BHE installation

Photos WTA, Worms, Germany
The second GSHP episode in Europe, 1970s-80s

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• The first Swiss experiments with BHE also started around that time, with the first modern BHE made of PE-pipes installed in 1980 (Rohner, 1991)

• Austria followed soon after.
The second GSHP episode in Europe, 1970s-80s

In Germany, the heat pump sales decreased rapidly, even with the oil price still high.

Major reason was insufficient quality and design expertise.

“A heat pump – no thanks, they do not work”

Development of heat pump sales and crude oil price in Germany 1978-1990 (after data from BWP)
The second GSHP episode in Europe, 1970s-80s

And Germany was not alone in that respect; France and Austria (a bit less pronounced) showed a similar pattern

Development of heat pump sales in France, Germany and Austria 1976-1990; all heat pump types considered, heat pump water heaters excluded (after data from BWP and EHPA)
The second GSHP episode in Europe, 1970s-80s

In the 1980s, interest in and development of BHE continued, but on a low market level.

Single family house in Wetzlar-Dutenhofen with BHE and heat pump (1986)

From brochure Geotherm GmbH, Germany
The second GSHP episode in Europe, 1970s-80s

Since the 1980s analytical as well as numerical methods have been developed for design calculation in shallow geothermal energy. Key methods for direct calculation (analytical methods), which work many times faster than numerical simulation, are based on work at the University of Lund, Sweden.

Screenshot from TFSTEP (1988)
The second GSHP episode in Europe, 1970s-80s

In 1985 a private company, Helmut Hund GmbH, started on a project for a full-scale research station for BHE in cooperation with the University of Giessen and an installing company, Geotherm GmbH.

The work was supported by the Federal ministry of research and technology (BMFT), and resulted in the Schwalbach GSHP research station (Sanner, 1986).
The second GSHP episode in Europe, 1970s-80s

Some results from Schwalbach GSHP Research Station

Recovery after long-term extraction experiment November 1986

Example of temperature distribution around BHE in Schwalbach GSHP-research station on 1.4.1987
The second GSHP episode in Europe, 1970s-80s

Similar Research installations were built in the following years in Europe:

• HTL Burgdorf, Switzerland (around 1995)
• EDF Lab les Renardières, France (around 2000)
• BRGM Orléans, France (around 2015)
• and other…
The impact of IEA (Advanced Heat Pumps IA)

In 1986, the German Schwalbach project became part of Annex 8 ‘Advanced In-Ground Heat Exchange Technologies’ of the IEA Heat Pump Implementing Agreement:

- The other partners were from Canada (NRC Ottawa), USA (ORNL) and Switzerland (ETH / Polydynamics).

- Each had either a test site for BHE, or used measurements from commercial plants with additional sensoring, like in Elgg ZH in Switzerland (Eugster, 1991).

Schwalbach GSHP Research Station, page from IEA HPC Newsletter 4/4, 1986
The impact of IEA (Advanced Heat Pumps IA)

Annexes on GSHP:
first in Annex 2, led by Sweden, then from 1986 in Annex 8 (CAN, CH, DE, USA), later many other
Also impact from IEA Energy Storage
(in the 1990s e.g. Annex 8, 12 and 13)
IEA Workshops on GSHP in 1986 (Albany NY) and 1991 (Montreal, CAN)
The impact of IEA (Advanced Heat Pumps IA)

IEA Heat Pump Conferences
1987 Orlando FL, USA
1990 Tokyo, Japan
1993 Maastricht, NL
1996 Toronto, CAN
…and more
Recovery of GSHP deployment in Europe, 1990s

Promotion of GSHP:
GSHP with BHE in Museum of Natural History, St Gallen, Switzerland

Photo from 1993

Connection to BHE outside the wall
Recovery of GSHP deployment in Europe, 1990s

Direct Cooling from BHE:

- Swiss patent filed in 1986
- First practical application, independently, in 1987 in Wetzlar, Helmut Hund GmbH
Recovery of GSHP deployment in Europe, 1990s to early 2000s

GSHP market in Germany: Politics and other drivers

- 1st RUS natural gas crisis in 1985
- 2nd oil price crisis
- Start of dedicated R&D in 1985
- 1998 first draft of VDI 4640

Number of GSHP sold annually in Germany (x 1000)
The status of GSHP technology and market today

Technology well developed, design knowledge exists:

• Design tools are available, from tables and simple software to numerical simulation.

• TRT is standard method to determine ground thermal parameters.

Typical TRT-setup at BHE on a site under development, in summer 2016 (left) and very mobile TRT on the same site in Northern Germany (right), photos Kahl/UBeG
The status of GSHP technology and market today

Technical standards have been developed or are under development:

• In the USA, IGSHPA has provided guidelines for the ground part of GSHP since about 1990; source for standards are ASHRAE and ASTM

• In Europe, first technical guideline AWP T1 on GSHP with BHE in 1990 in Switzerland (latest version AWP T1-T9 from 2007)

• Most comprehensive guideline in Europe is Germany VDI 4640 (5 parts)
The status of GSHP technology and market today

Technical standards have been developed or are under development:

<table>
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<tr>
<th>Country</th>
<th>Standards</th>
<th>Year</th>
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<tr>
<td>AT</td>
<td>ÖWAV-Regelblatt 207</td>
<td>2009</td>
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<td>DE</td>
<td>DIN 8901, VDI 4640-1 to 4640-5</td>
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<td>CH</td>
<td>SN 546 384/6, SN 546 384/7</td>
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<td>SE</td>
<td>SGU Normbrunn-07</td>
<td>2008-2016</td>
</tr>
<tr>
<td>UK</td>
<td>DECC MIS 3005 (with sizing tables MCS 022), GSHPA Closed-loop Vertical Borehole, GSHPA Thermal Pile</td>
<td>2011-2012</td>
</tr>
</tbody>
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New CEN/TC 451 „Geothermal and Water Boreholes“ established in 2016, secretariat with AFNOR
The status of GSHP technology and market today

The total number of GSHP installations in place in Europe at the end of 2015 can be estimated at well above 1.7 million.

The annual GSHP sales in Europe in 2015 totaled around 80,000 units, approximately 34,000 of which (44%) were in the Nordic countries.

The total installed capacity in Europe approached 23 GW\textsubscript{th} in 2015.

From EGEC Market Report 2016, published 10.5.2017
The status of GSHP technology and market today

Annual heat pump sales in France, Germany and Switzerland in 2010-2016, and the share of geothermal in total sales

From EGEC Market Report 2016, published 10.5.2017
The status of GSHP technology and market today

Examples of projections and achievements in four European countries:
The National Renewable Energy Action Plans (NREAPs) from 2010 show a pathway to achieve the 2020 goals, and some countries are lagging behind

From EGEC Market Report 2016, published 10.5.2017
The status of GSHP technology and market today

Today, the barriers against further market growth of shallow geothermal can be divided into 3 groups:

• Economic shortcomings for heating mode in certain countries (fossil too cheap, electricity too expensive)
• Insufficient awareness with the public (potential consumers), the planners/installers, and the regulatory administration
• Exaggerated licensing requirements, driving cost and uncertainty

Subsidies and grants can only partly offset these barriers.

And for the technical development we must accept:
We are under the control of geology – we cannot change the rock outside the borehole
And the future – what might be achieved?

The topics for R&D advancing towards these targets in Europe are also listed in the Common Roadmap. The most important as to the author’s view are:

• Improved vertical borehole drilling technologies to enhance safety and reduce cost of BHE installations, improved installation technologies and geometries for ground heat exchange technology.

• Improved pipe materials for BHE and horizontal ground loops. New pipes for higher temperatures. Better thermal transfer fluid.

• Integration of design of the shallow geothermal system and building energy system with regard to optimum thermal use and operational strategy.

http://www.rhc-platform.org/publications/
And the future – what might be achieved?

The topics for R&D advancing towards these targets in Europe are also listed in the Common Roadmap. And in a more general and non-technological sense:

- Creation of a new European wide database to map conductivities and potential (to 100 m depth or more) and feasibility of vertical BHE systems. (author’s remark: and with link to the new European Geological Data Infrastructure EGDI)

- Measures to increase awareness, harmonisation of shallow geothermal standards, EU-wide training certificate for shallow geothermal installers.

http://www.rhc-platform.org/publications/
And the future – what might be achieved?

Reducing the Borehole Thermal Resistance by improving pipe materials and grouting

Influence of pipe material, ground 2.5 W/m/K

Graph from GROUNDHIT project, 2005 (calculations Sanner, using EED)
And the future – what might be achieved?

GSHP and BHE efficiency as shown in the „Strategic Research and Innovation Agenda for Renewable Heating & Cooling“ of the European Technology Platform on Renewable Heating and Cooling, March 2013

The relevant item in the „Enabling Technologies“ section of the document
And the future – what might be achieved?

New EU-Project GEOCOND is working towards the goal of improved materials:

Started 1st May 2017, duration 42 month

10 partners from 7 countries (DE, IR, IT, SE, SP, TR, UK), mainly from material sciences in plastics, cement, grouting

Targets/Objectives:

• Pipe Material: Development and testing of new pipe materials with improved conductivity and increased resistance to high temperatures

• Grouting Material: Development and testing of new technologies to improve thermal properties of the grouting of the BHE

• The development of a respective Material Decision Support System

Website: http://cordis.europa.eu/project/rcn/209743_en.html
(own website coming soon)
Ground Source Heat Pumps – so good that they are shown on stamps from Liechtenstein!

Thank you for your attention!